BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 05071

SUBJECT: Alternate Electrical Power and Oxygen Storage Systems for the Skylab CSM
Case 620

DATE: May 28, 1970

FROM: J. J. Sakolosky

ABSTRACT

The Skylab CSM electrical power and cryogenic storage systems consist of two fuel cells, two supercritical hydrogen tanks, and two supercritical oxygen tanks. As a result of the Apollo 13 cryogenic tank failure, two alternate electrical power and oxygen storage systems which do not utilize supercritical oxygen tanks have been examined with respect to Skylab CSM requirements. Both alternate systems use LM descent stage gaseous oxygen tanks. One system utilizes fuel cells; the other utilizes batteries to provide electrical power. Based on weight and volume criteria, both alternate systems are capable of meeting Skylab CSM requirements. Provision of additional consumables for longer duration independent operation of the CSM, or for operating margins, causes more rapid weight and volume increases in either of the alternate systems than in the baseline system.

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MEMORANDUM FOR FILE

Introduction

The purpose of this memorandum is to examine the feasibility, from weight and volume standpoints, of replacing the current Skylab CSM electrical power and oxygen storage system with several alternate configurations which do not utilize supercritical cryogenic oxygen tanks. The motivation for conducting this study was the failure of the cryogenic oxygen tank in Apollo 13. This memorandum should not be construed as a recommendation to change the current Skylab baseline configuration; it is rather an initial evaluation of several alternate system configurations in the event that the results of the Apollo 13 accident investigation prohibit the use of Apollo Block II cryogenic oxygen tanks in the Skylab CSM.

The Skylab baseline system consists of two Pratt and Whitney fuel cells, two Beech cryogenic hydrogen tanks, and two Beech cryogenic oxygen tanks. Figure 1 illustrates the location of this hardware in Sector IV of the Service Module. The first alternate configuration (hereafter referred to as the fuel cell/gaseous system) consists of two Pratt and Whitney fuel cells, two Beech cryogenic hydrogen tanks, and the number of LM descent stage gaseous oxygen tanks required to meet consumables requirements. The second alternate configuration (hereafter referred to as the battery/gaseous system) uses LM descent stage batteries to provide electrical power and LM descent stage gaseous oxygen tanks to store ECS oxygen.

Determination of Consumables

A number of assumptions have been made in determining the electrical power system and environmental control system consumables required. These assumptions are listed below.

1. The CSM is active for 12 hours after docking.

2. Metabolic oxygen is consumed at a rate of 2.0 lbs/man/day.

3. 30 pounds of IVA oxygen are required from the CSM (10 lbs/hr for 3 hours).

4. The CSM atmospheric leakage rate is 2.4 lbs/day prior to docking; it is 3.6 lbs/day after docking.

5. The CSM return time is 7.0 hours. This is taken to be the time from installation of the MDA hatch to splashdown.

The power profile used to determine EPS consumables is shown in Figure 2. The profile for each of the alternate system configurations is identical from liftoff to CSM deactivation after docking. However, the pre-launch energy requirements for the systems differ, and therefore different amounts of consumables are required.

For the baseline system, the cryogenic oxygen and hydrogen tanks are pressurized 35 hours prior to liftoff. Normal boiloff from the tanks is directed through the fuel cells to provide 1200 watts of pre-launch power. Any additional power required by the spacecraft is supplied by ground support equipment (GSE). At three hours prior to liftoff, the load is switched entirely to the spacecraft electrical power system.

The fuel cell/gaseous system does not have to contend with boiloff from the gaseous oxygen tank, but boiloff from the cryogenic hydrogen tank still occurs after the tank is pressurized 35 hours before liftoff. GSE may be used to supply gaseous oxygen to complement the hydrogen flow to the fuel cells until 17 hours before liftoff when the mobile service structure is removed from the vehicle. Subsequent to this time, oxygen must be supplied from the gaseous stores aboard the spacecraft.

The prelaunch energy requirements are even less for the battery/gaseous system. Electrical power may be supplied to the spacecraft by means of the launch umbilical tower until just prior to liftoff. The assumption in this memorandum is that the batteries are switched to the spacecraft bus 1 hour prior to liftoff.

Under the listed assumptions, the CSM supplies its own power for a period of 12 hours after docking. The rendezvous and dock period is 7.5 hours for an M = 5 rendezvous and 24 hours for an M = 16 rendezvous. The ascent time is approximately 10 minutes.

To meet environmental control system (ECS) requirements, consumable oxygen must be provided for crew metabolism, spacecraft atmospheric leakage, and IVA. The requirements will be the same regardless of the electrical power system configuration.

A summary of the EPS and ECS consumables is given in Table I. Notice that as a result of the prelaunch differences the oxygen requirements of the fuel cell/gaseous system are less than the baseline system. The hydrogen requirements are the same, however, since the cryogenic H_2 tanks for both configurations are pressurized at the same time in the countdown. It should be noted that the consumable quantities specified in Table I are exactly the requirements on the systems as previously defined. No margins have been included in any of the quantities shown.

System Weights and Volumes

Tables II, III, and IV specify the system component and total weights for each of the alternate configurations. Once again, the systems are sized just to meet requirements. No margins are included in the consumable quantities. The weights for plumbing, valves, support structure, and the electrical harness have been estimated. For the Skylab baseline system they have been apportioned from an inclusive figure; thus, the total weight for that system is accurate.

Table V compares the total system weight and volume for each of the configurations. The volumes include the applicable tank volume, fuel cell volume, and battery volume. The first two columns of Table V represent the weights and volumes of systems sized exactly to meet requirements. The fuel cell/gaseous system and the battery/gaseous system both weigh less and occupy less volume than the baseline system under these circumstances. The last two columns of Table V represent systems which store excess consumables. That is, the systems are capable of providing 48 hours of electrical power at 1850 watts and 48 hours of metabolic and spacecraft atmospheric leakage oxygen over the required amounts. Notice that the weight and volume of the alternate systems increase at a faster rate than the baseline system. This results from the additional storage tanks and batteries which must be added to the fuel cell/gaseous and battery/gaseous systems; excess consumable storage capacity already exists in the baseline system so that its weight increase is due to additional consumables only. The 48 hour margin was chosen rather arbitrarily to illustrate the difference in system growth rate as consumables storage requirements increase. Not surprisingly, the battery/gaseous system weight increases rapidly as electrical energy requirements grow. Based strictly on weight and volume requirements, the fuel cell/gaseous configuration appears to be a feasible alternative to the baseline system for a fairly broad range of consumables requirements.

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Attachments
  Figures 1-2
  Tables I-V

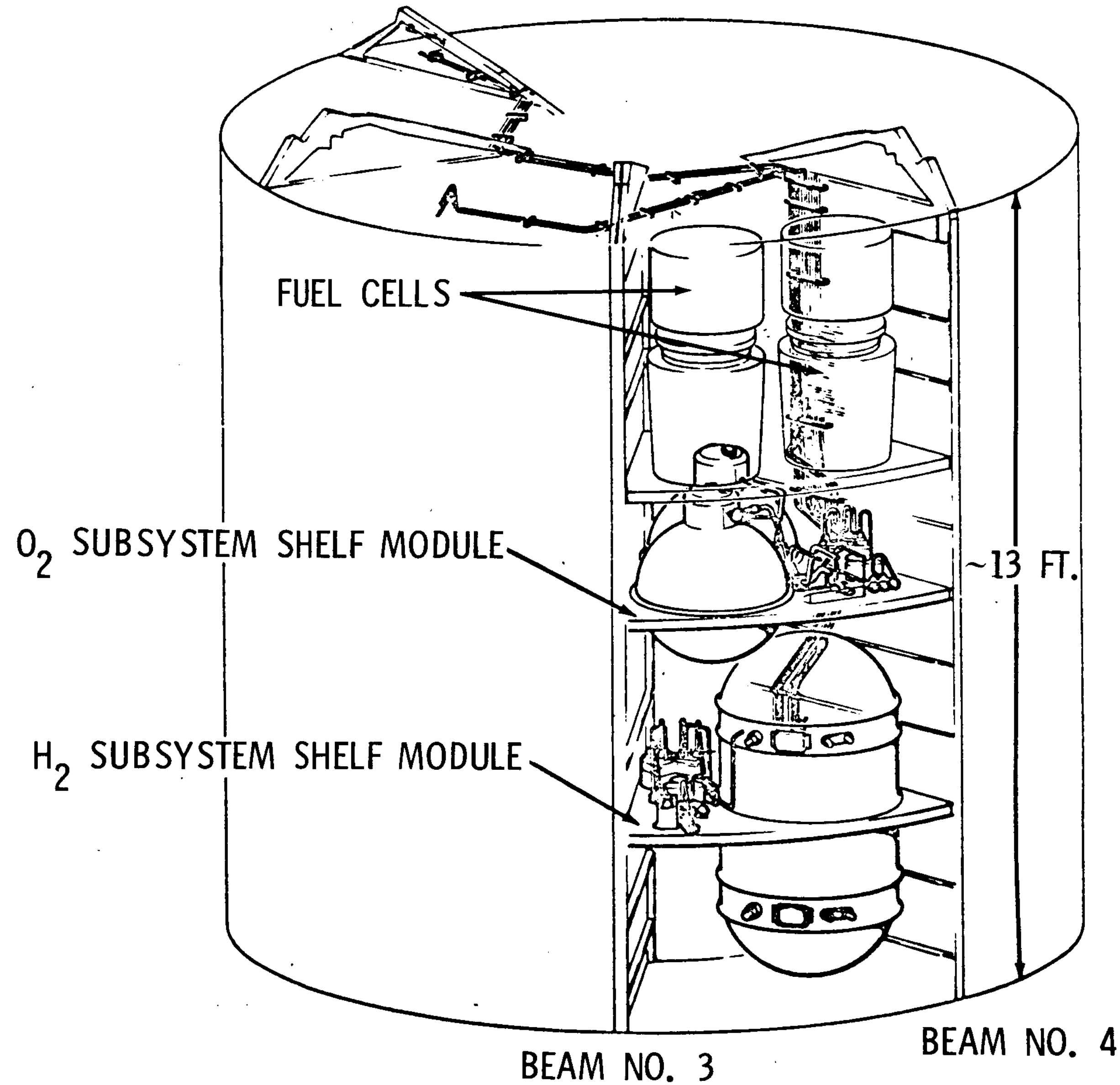

FIGURE 1 - CRYOGENIC STORAGE AND FUEL CELL CONFIGURATION

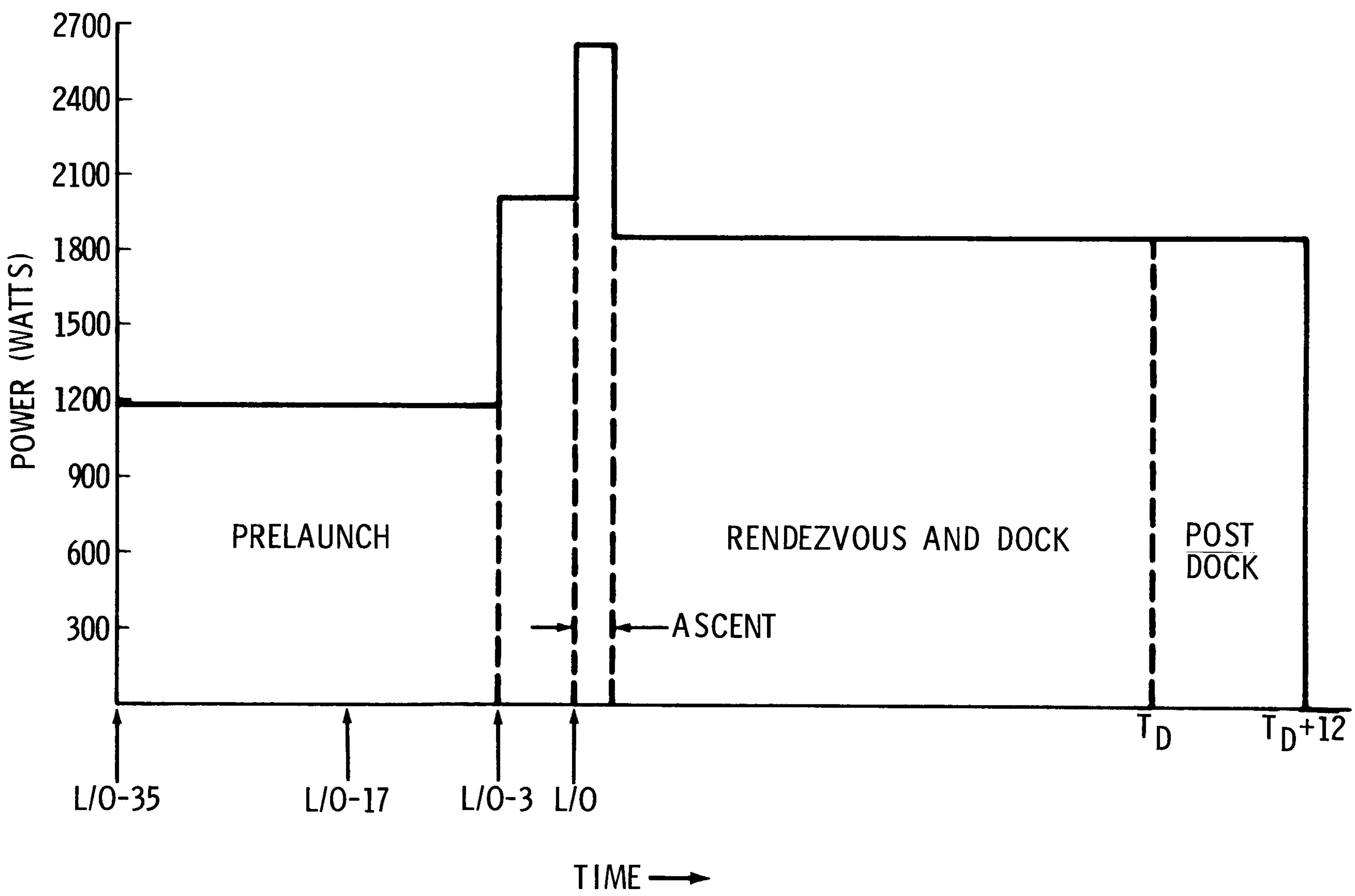

FIGURE 2 - CSM POWER PROFILE

TABLE I. CONSUMABLES WEIGHT FOR ALTERNATE SYSTEM CONFIGURATIONS

	M=5	M=16
SKYLAB BASELINE		
EPS OXYGEN	56.4 LBS	78.3 LBS
EPS HYDROGEN	7.1 LBS	9.8 LBS
FUEL CELL/GASEOUS O_2		
EPS OXYGEN	41.9 LBS	63.9 LBS
EPS HYDROGEN	7.1 LBS	9.8 LBS
BATTERY/GASEOUS O_2		
NUMBER OF BATTERIES	4	6
WEIGHT OF BATTERIES	620.0 LBS	930.0 LBS
ECS OXYGEN	40.0 LBS	45.7 LBS

TABLE II. WEIGHT OF SKYLAB BASELINE SYSTEM

	M = 5	M = 16
Two P & W Fuel Cells	480.0 LBS	480.0 LBS
One Dummy Fuel Cell	25.0	25.0
Two Cryogenic O_2 Tanks	161.8	161.8
Cryogenic O_2 Plumbing, Valves, Support	100.0	100.0
Two Cryogenic H_2 Tanks	137.0	137.0
Cryogenic H_2 Plumbing, Valves, Support	100.0	100.0
Fuel Cell Plumbing	100.0	100.0
Electrical Harness	450.0	450.0
Cryogenic Oxygen	96.4	124.0
Cryogenic Hydrogen	7.0	9.8
TOTAL:	1657.3 LBS	1687.6 LBS

TABLE III. WEIGHT OF FUEL CELL/GASEOUS SYSTEM

	M = 5	M = 16
Two P & W Fuel Cells	480.0 LBS	480.0 LBS
One Dummy Fuel Cell	25.0	25.0
LM Descent Stage GOX Tank	114.0 (2 tanks)	171.0 (3 tanks)
Gaseous O_2 Plumbing, Valves, Support	44.0	66.0
Two Cryogenic H_2 Tanks	137.0	137.0
Cryogenic H_2 Plumbing, Valves, Support	100.0	100.0
Fuel Cell Plumbing	100.0	100.0
Electrical Harness	450.0	450.0
Gaseous Oxygen	81.9	109.6
Cryogenic Hydrogen	7.1	9.8
TOTAL:	1539.0 LBS	1648.4 LBS

TABLE IV. WEIGHT OF BATTERY/GASEOUS SYSTEM

	M = 5	M = 16
LM Descent Stage Batteries	620.0 LBS (4 batteries)	930.0 LBS (6 batteries)
LM Descent Stage GOX Tank	57.0 (1 tank)	57.0 (1 tank)
Gaseous O_2 Plumbing, Valves, Support	22.0	22.0
Electrical Harness	450.0	450.0
Gaseous Oxygen	40.0	45.7
TOTAL:	1189.0 LBS	1504.7 LBS

BELLCOMM, INC.

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TABLE V. ALTERNATE CONFIGURATION WEIGHTS AND VOLUMES

	CONSUMABLES SIZED AS REQUIRED		CONSUMABLES SIZED WITH 48 HOUR MARGIN	
	M=5	M=16	M=5	M=16
WEIGHT				
SKYLAB BASELINE	1657 LBS	1687 LBS	1746 LBS	1776 LBS
FUEL CELL/GASEOUS	1539 LBS	1648 LBS	1786 LBS	1895 LBS
BATTERY/GASEOUS	1189 LBS	1505 LBS	2370 LBS	2841 LBS
VOLUME				
SKYLAB BASELINE	46 FT^3	46 FT^3	46 FT^3	46 FT^3
FUEL CELL/GASEOUS	43 FT^3	46 FT^3	49 FT^3	52 FT^3
BATTERY/GASEOUS	7 FT^3	9 FT^3	16 FT^3	19 FT^3